Aquifer Tests in Carbonate Rocks Overlain by Glacial Sediments in North-Central Ohio[1]

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ABSTRACT. **The upper 25 to 30 meters (m) of the carbonate-rock aquifer system in north-central Ohio was tested at three sites in 1987 to determine the feasibility of constructing the Superconducting Super Collider (SSC). The aquifer system consists of a sequence of Silurian dolomites and Devonian limestones which is generally overlain by glacial deposits. Although the bedrock units have been separated in terms of age and lithologic characteristics, they function as a common hydrologic unit. Values of transmissivity and the coefficient of storage range from 15 to 745 m^2/day, and 1.8 x 10^{-5} to 9.8 x 10^{-4}, respectively. Water-bearing zones above and below the depth of production in test wells responded to pumping, but the vertical communication was usually not as well developed as horizontal communication. In one test, nested wells completed separately in the bedrock and glacial sediments indicated that the two systems behaved as a single hydrologic unit. Fracture systems in the carbonate-rock aquifer were detected beneath greater than six m of glacial deposits by close inspection of low-level black-and-white infrared aerial photographs. Observation wells located on the fracture systems indicated relatively higher directional transmissivities. The results of the investigation indicated that ground water would have been a factor during construction of the SSC facility. Dewatering and depressurization wells, grouting, and sumps would have been required to control inflows from the aquifer system.**

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INTRODUCTION

A ground-water investigation was made in north-central Ohio (Fig. 1) to support the siting proposal for the Superconducting Super Collider (SSC) submitted jointly by Ohio and West Virginia. The SSC was a proposed 95- to 160-km circular underground racetrack for counter-rotating beams of protons which are kept on track by powerful magnets. Well drilling and aquifer tests were performed from May through June, 1987, to determine the hydraulic characteristics of the upper portion of the carbonate rocks and evaluate the hydraulic connection with the overlying glacial deposits. Results were incorporated into an assessment of ground-water inflow prepared for the proposed SSC tunneling and underground construction project.

Baseline geologic and hydrologic data and technical support for the investigation were provided by the Division of Geological Survey and the Division of Water, Agencies of the Ohio Department of Natural Resources (ODNR). Previous investigations of significance were performed by Norris (1979), Norris and Fidler (1973), ODNR (1972), and Norris and Fidler (1971). The hydraulic properties of relatively thick beds of carbonate rocks in northwestern, southwestern, and central Ohio were studied in these reports.

MATERIALS AND METHODS

The Aquifer System

The aquifer system consists of a sequence of carbonate rocks overlain by glacial deposits (Fig. 2). The carbonate rocks are Devonian limestones and Silurian dolomites. Stratigraphic units (youngest to oldest) include the Olentangy Shale, Delaware Limestone, Columbus Limestone, the Salina Undifferentiated (dolomites), the Tymochtee Formation (dolomites), the Greenfield Dolomite, and the Lockport Dolomite.

The carbonate rocks are saturated throughout most of the region. Ground water, typically under artesian pressure, is confined by less permeable glacial deposits and

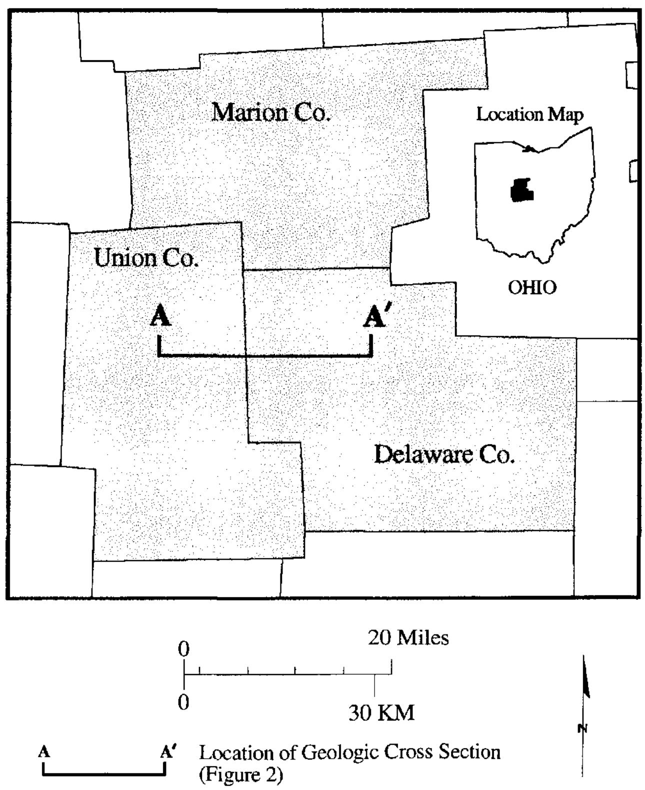

FIGURE 1. Location of area of investigation.

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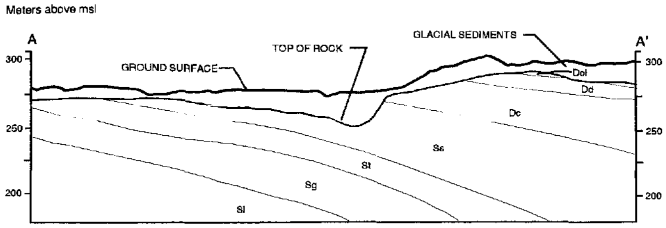

FIGURE 2. Geologic cross section of study area (after Collins and Pavey 1987). Legend: Olentangy Shale (Dol); Delaware Limestone (Dd); Columbus Limestone (Dc); Salina Undifferentiated (Ss); Tymochtee Formation (St); Greenfield Dolomite (Sg); Lockport Dolomite (Sl).

poorly permeable bedrock strata overlying productive zones. The potentiometric surface of the carbonate-rock aquifer is above the top of bedrock but normally below land surface, although flowing wells occur locally.

The glacial deposits, commonly 6.0 to 9.0 m thick, are also water bearing. Water table conditions generally exist in the glacial deposits, although water in sand and gravel layers interbedded with till may occur under artesian conditions. Nested wells installed at the test sites showed that the difference in hydrostatic head between the carbonate-rock aquifer and the glacial deposits was very small, less than 3.0 cm in places. Water levels in the two aquifers are nearly in equilibrium.

Recharge - Discharge

Ground-water recharge occurs from precipitation that falls both regionally and locally. Many of the underlying carbonate rocks subcrop beneath the glacial till between western Union and Marion counties (Fig. 1) and an upland area approximately 30 to 40 km west of the site. Recharge enters the subcrops from nearly 90 cm of annual precipitation. Ground water in the carbonate rocks moves from the recharge areas in the west toward areas of discharge near the eastern margin of the site.

Locally, ground water is recharged by infiltration of precipitation that generally proceeds downward through the glacial deposits. Movement is enhanced by fractures in the till and coarser deposits (Strobel 1993). Where water levels in glacial deposits are above the level of the potentiometric surface in the underlying carbonate rocks, ground water will move vertically from the glacial deposits downward into the bedrock. Local recharge occurs in this manner throughout the site, primarily during the spring in areas of relatively high elevation.

Ground water is discharged from the bedrock by upward leakage into the overlying glacial deposits. This process occurs where the potentiometric surface in the bedrock is higher than the water table in the glacial deposits. Local ground water discharge generally occurs in low-lying areas and along streams which intersect the water table.

The elevation of the potentiometric surface (Fig. 3) indicates that the Olentangy and Scioto River valleys are major discharge areas for the carbonate-rock aquifer. It is evident from the contours that ground water moves towards the rivers from both sides of the streams. It appears that the rivers act as linear sinks, with water moving towards the channels in a manner similar to a line of pumping wells. An area with a nearly flat gradient exists between the Scioto and Olentangy Rivers (Fig. 3). The flat gradient indicates a ground water divide between flow moving west to the Scioto River and east to the Olentangy River.

Drilling and Aquifer Test Design

Drilling and well testing were conducted from May 4 through June 1, 1987. Three locations near Waldo, Ostrander, and southwest of Richwood (Fig. 3) were selected in order to test the water-yielding properties of the carbonate rocks in areas where bedrock fractures were inferred. Close inspection of low-level black-and-white infrared aerial photographs at a scale of 1:24,000 revealed the presence of linear features in the bedrock beneath the glacial deposits. The linear features are darker in tone, representing zones of relatively higher soil moisture content and were interpreted to be bedrock fracture traces. Pumping and observation wells were located on or as close to the linear features as possible to determine the hydraulic characteristics in areas which could produce large ground water inflows in the SSC tunnel during construction.

Figure 4 shows typical sections of the geology and well completion features at the test sites. The wells were installed and developed by air rotary drilling. Fractured or weathered zones encountered within competent bedrock strata are noted on the drilling logs (Fig. 4). In general, one well at each site was designed as a large diameter (30-cm) pumping well. The pumping well and

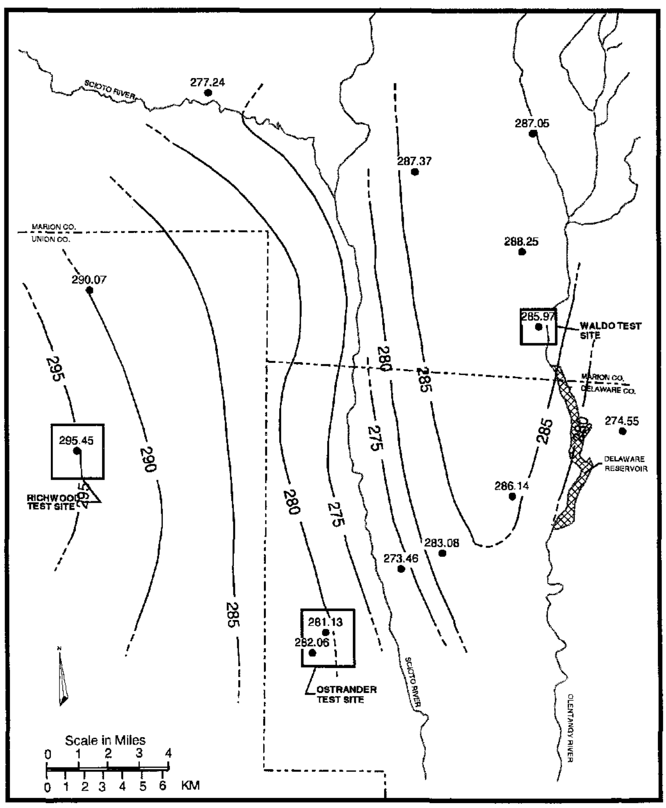

FIGURE 3. Elevation of potentiometric surface in carbonate rocks. Legend: 281.13 = potentiometric surface elevation (meters above msl); • = well location.

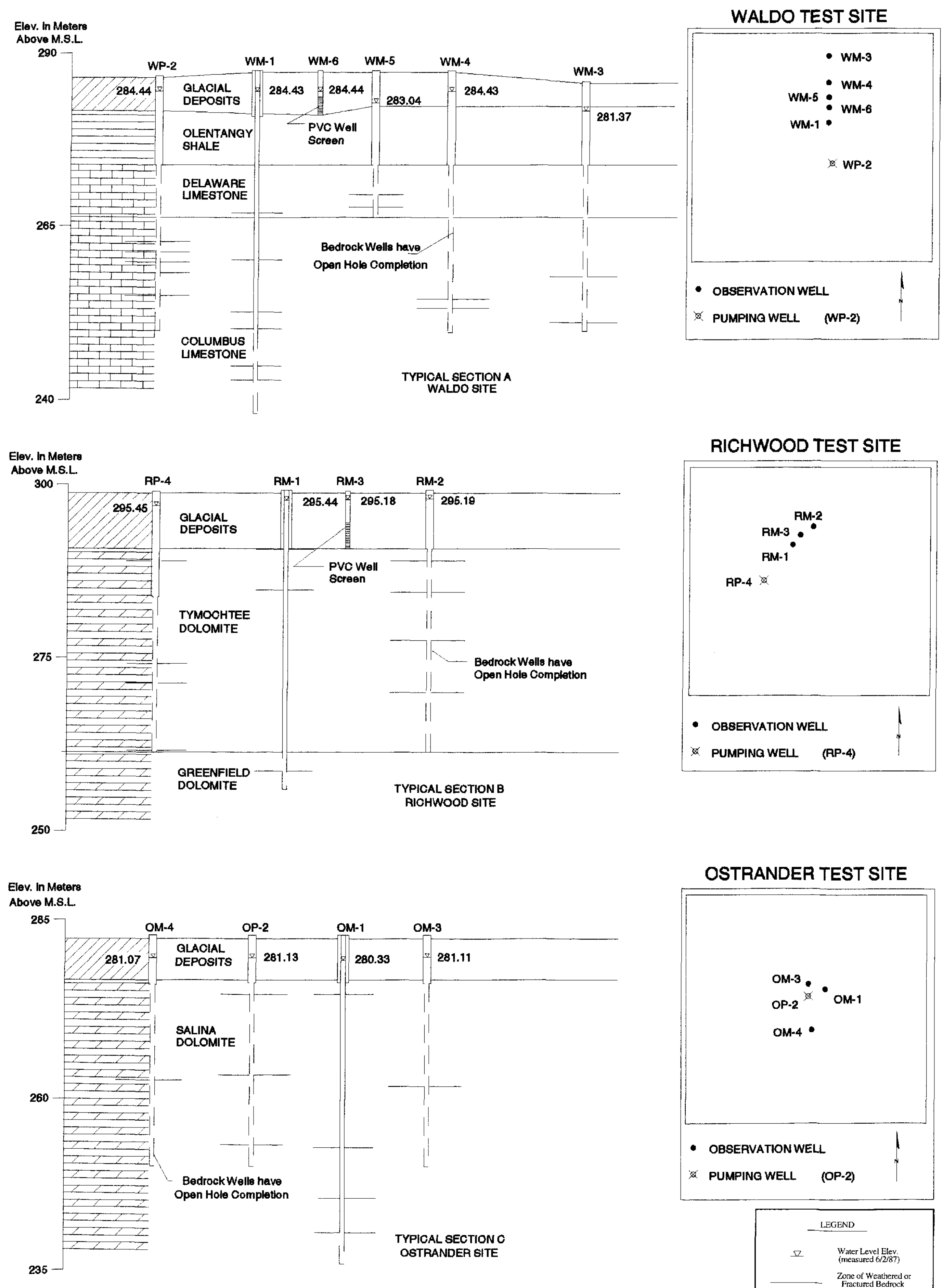

FIGURE 4. Typical sections showing hydrogeology and well completion characteristics at test sites.

one or two observation wells were completed with similar construction in water producing zones in the upper 30 m of the underlying bedrock. Additionally, one well was completed in water producing zones below the final depth of completion of the pumping well, and one well was completed in the glacial deposits (Fig. 4). Special care was taken during the installation of grout seals to prevent cross communication between water bearing zones via the annular space.

The wells were designed to determine the vertical head distribution and the degree of communication within the system, as well as general aquifer properties. Tests were conducted in three phases as suggested by Eagon and Johe (1972): 1) a two-hour pumping trial was made to determine the best pumping rates for subsequent tests and to verify that the equipment was operating satisfactorily; 2) a step-drawdown test, with each step consisting of a successively higher pumping rate, was conducted to determine information about the character and depth of the water yielding zones and to verify the appropriate pumping rate to be used in the subsequent constant-rate drawdown test. Each step was a two-hour period with the entire test consisting of four steps. Recovery was monitored in the wells for approximately 14 hours; 3) constant-rate drawdown tests were made for approximately 24 or 48 hours. Recovery was usually monitored for a period of time equal to that of the drawdown tests.

Data from the aquifer tests were analyzed, and values for transmissivity and storage coefficient were calculated using a number of methods including semilogarithmic and logarithmic plots of drawdown versus time, semilogarithmic plots of drawdown versus distance, and semilogarithmic plots of recovery versus time. Leaky-aquifer type curves were also used to analyze logarithmic plots of drawdown versus time. The analytical methods were used with caution, since carbonate-rock aquifers are rarely homogeneous and isotropic, and violate assumptions used to develop the equations.

RESULTS

Waldo

A yield of 19 l/sec was maintained in the pumping well WP-2 during the 24-hour constant-rate test. The pumped well was completed in water producing zones in the upper portion of the Columbus Limestone (Fig. 4, Section A). Analysis of time-drawdown data recorded in observation wells WM-4 and WM-3 showed transmissivities of approximately 140 and 745 m^2/day, respectively. The observation wells were completed in a similar fashion to the pumped well (Fig. 4, Section A) and were north and northeast of the pumped well. The well to the northeast (WM-3) was located on a northeast-southwest trending linear feature which most likely represents a fracture system responsible for the higher directional transmissivity.

The observation well completed in the glacial sediments (WM-6) showed a rapid response to pumping even though it was separated from the Columbus Limestone by approximately 6.0 m of the Olentangy Shale and the Delaware Limestone (Fig. 4, Section A). The response shows that the artesian system in the carbonate-rock aquifer has a high degree of interconnection with the glacial sediments despite confining layers.

Time-drawdown plots for the observation well completed in the Delaware Limestone (WM-5) and the well completed in water-producing zones in the lower portion of the Columbus Limestone (WM-1) were also analyzed. These wells were nested with WM-4 (Fig. 4, Section A) which was completed in the zone of production. The drawdown produced in wells WM-5 and WM-1 was not as large as that in WM-4. The data indicate that a decrease in pressure head in a specific zone of the carbonate-rock aquifer brought about by pumping will cause both upward and downward leakage, but vertical communication is not as well developed as horizontal communication at this site.

Richwood

Two constant-rate discharge tests were performed near Richwood (Fig. 3) to determine the aquifer characteristics of the Tymochtee Formation and the upper portion of the Greenfield Dolomite (Fig. 4, Section B). In the first test, a production rate of 27 l/sec was maintained in well RP-4 for 26 hours. RP-4 was completed in the Tymochtee Formation. Observed drawdown in wells RM-2 and RM-3 was approximately 1.2 m at the end of the test. Well RM-2 was completed in the Tymochtee Formation similar to the pumping well, and well RM-3 was completed in the glacial sediments.

Wells RM-2 and RM-3 had a similar drawdown response to pumping. The geologic logs show that sand and gravel overlie an intensely fractured zone of the dolomite (Fig. 4, Section B). The fractured dolomite and the sand and gravel acted as a single hydrologic unit. The volume of leakage which entered the cone of depression from the overlying glacial sediments was significant as shown by the time-drawdown data in well RM-3.

The upper portion of the Greenfield Dolomite was also tested using RM-l as the pumping well. The results indicated that the transmissivity of this bedrock section was relatively low, approximately 15 m^2/day. Leakage was evident in the time-drawdown plots, and 15 cm of drawdown was produced in well RM-3 which was completed in the glacial sediments. A highly transmissive section known as the Newburg Zone (Norris and Fidler 1973) exists at or near the base of the Greenfield Dolomite. It is likely that some ground water moved from the Newburg Zone by upward leakage into the zone of production, although no wells were completed in this portion of the Greenfield Dolomite for the test.

Ostrander

A 48-hour, constant-rate discharge test near Ostrander was performed to determine aquifer characteristics of the Salina Undifferentiated (dolomites). Existing domestic and test wells were monitored in addition to the observation wells (Fig. 4, Section C). Observation wells relatively close to the pumped well (less than 120 m) showed transmissivities in the range of 240 to 300 m^2/day and a storage coefficient of approximately of 1×10^{-5}.

Wells more distant from the pumping center (600 to 1,400 m) showed transmissivities between 400 and 550 m^2/day and a storage coefficient near 1×10^{-4}.

The transmissivities and storage coefficients obtained from wells close to the pumping center were relatively lower in value and appear to represent local properties in the zone of production (Saline Undifferentiated). It is believed that the cone of depression intersected additional fractured and weathered zones as it enlarged during the test. The fractured and weathered zones provide greater storage and secondary permeability in the carbonate rocks and increase communication with deeper geologic sections within the aquifer. The relatively high values of transmissivity and storage therefore represent the contribution of a greater thickness and regional conditions in the carbonate-rock aquifer.

DISCUSSION

Results from four aquifer tests at Ostrander, Waldo, and Richwood are summarized in Table 1. Values determined from other tests in the carbonate-rock aquifer, including those at Big Island (Norris 1979) and at various locations in central Ohio, are also listed for comparison. Values of transmissivity from the four tests ranged between 15 m^2/day and 745 m^2/day. The wide range in values demonstrates the anisotropic, heterogeneous nature of the carbonate rocks. The mean transmissivity for the three sites was fairly consistent with values ranging between 220 and 335 m^2/day. The values determined for the coefficient of storage are between 1.8×10^{-5} and 9.8×10^{-4} and are indicative of an artesian aquifer system.

Values of transmissivity for the three sites are generally lower than the results obtained by Norris (1979) and the ODNR (1972). However, in previous investigations, thicker sequences of the carbonate-rock aquifer were tested. The shallower depth of penetration at Waldo, Richwood, and Ostrander explains the relatively low transmissivities.

The response to pumping measured in observation wells at both the Waldo and Richwood sites shows a high degree of interconnection between the carbonate-rock aquifer and the glacial sediments. The time-drawdown data from the test at Richwood indicate that the volume of leakage was significant. Norris (1979) also found that glacial till can supply large quantities of water to the carbonate-rock aquifer at the Big Island site.

CONCLUSIONS

The aquifer system underlying the area proposed for the SSC in north-central Ohio consists of a series of carbonate rocks overlain by glacial deposits. Although the bedrock units have been separated in terms of age and lithologic characteristics, they function as a common hydrologic unit. Aquifer tests indicate that a decrease in pressure head in a specific zone of the carbonate-rock aquifer brought about by pumping will cause upward and downward leakage. The vertical communication is generally not as well defined as horizontal communication.

Observation wells installed at the test sites indicated that the difference in hydrostatic head between the carbonate-rock aquifer and the glacial sediments is very small. Water levels in the two aquifers are nearly in equilibrium. Aquifer tests showed the two aquifers are interconnected by leakage, and fractured bedrock overlain by coarse glacial sediments responded to pumping as a single hydrologic system.

The investigations and aquifer tests showed that ground-water inflows would have been an important consideration during tunneling and underground construction for the proposed SSC project. Construction could have proceeded without elaborate water control in competent bedrock strata, such as the upper portion

TABLE 1

Summary of aquifer test results.

Site	Pumping Rate (l/sec)	Duration of Tests	Transmissivity (m^2/day) Range	Mean	Storage Coefficient Range	Mean	Bedrock Tested
Ostrander	22	48 hours	240-550	335	1.8×10^{-5} - 9.8×10^{-4}	3.3×10^{-4}	Salina (Ss)
Waldo	19	24 hours	140-745	330	2.7×10^{-5} - 5.3×10^{-4}	2.8×10^{-4}	Columbus (Dc)
Richwood	27	26 hours	160-300	220	1.0×10^{-4} - 6.3×10^{-4}	3.7×10^{-4}	Tymochtee (St)
	6	24 hours	15				Upper Greenfield (Sg)
Big Island**	23	90 days	300-490	330	1.0×10^{-4} - 7.5×10^{-4}	1.1×10^{-4}	Greenfield (Sg)/ Lockport (Sl) (Composite Wells)
Central Ohio Data***	5-175	24 hours	305-1,045	355*	—		Composite Wells in Ss, Dc, St, Sg, and Sl

*Single Well Tests
**Norris 1979
***ODNR 1972

of the Greenfield Dolomite. However, control of ground water would have been more difficult in fractured or weathered bedrock or where the tunnel roof was near the contact with the glacial sediments.

Pumping wells installed in the carbonate-rock aquifer and the glacial sediments would have been required to control inflows and reduce artesian pressure during construction. Sumps within the tunnel and other excavations could also have been used to collect and divert ground water. Drilling and grouting ahead of construction and pregrouting shaft excavations would reduce the possibility of sudden inflows at locations where fractured and weathered zones were likely. Infiltration from overlying water-bearing material could be reduced by alignment of the tunnel below the contact between glacial sediments and the underlying bedrock.

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